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STUDIES OF COTTON ROOT ROT AT GREENVILLE, TEX.

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ROOT-ROT RECORDS AT THE GREENVILLE STATION

In each year since 1920 records have been made of the location and distribution of root rot on all of the field plots at the United States Cotton-Breeding Field Station at Greenville, Tex. The diseased areas are carefully mapped to show the distribution of root rot in each row, as indicated by dead plants late in the season. The measurements have been recorded to the nearest half foot, and the limit of infection taken as a point midway between a living and a dead plant. These maps, showing the location and distribution of the disease at the end of each growing season for a period of eight years, form the basis of this report and indicate that the normal growth of the diseased spots is ringlike, and that they usually spread in a more or less definite and orderly manner.

At Greenville, the plants begin dying of root rot about the first of July when normally they have reached a height of about 18 inches. In some years the mortality of plants is high early in the season, while in other years heavy losses do not occur until late in the season.

Some of the observations and experiments at Greenville are of the same nature as those that have been reported in Arizona and at San Antonio, Tex., while others are of somewhat different character.

PERSISTENCE OF INFECTED AREAS

That cotton root rot is native to many districts is shown by the disease appearing in fields planted for the first time to cultivated crops on virgin land.

It is not uncommon to find in fields which have long been planted to cotton, root-rot spots which appear to be new, although their origin in most cases is not definitely accounted for. Such cases as

have been observed at the Greenville station have practically always resulted from the breaking down of a large spot into a number of small isolated points of infection, all located within the area of old infection, but otherwise bearing no definite relation to the spot of the previous year. These isolated small spots might easily be taken to represent new infection rather than the reinfection which they really are, and their occurrence may account for some of the reports that root-rot infection is spreading rapidly in certain regions. Apparently one is not justified in drawing conclusions as to whether a spot is new or old until after making a careful study of an accurate set of records on the field kept over a long period of years.

A different form of small isolated spot has sometimes been observed which appears to be of recent origin. In 1927 a number of these spots were observed very late in the season on several different station plots. These apparently new points of infection, consisting of 1 to 8 dead plants, always occurred just a few feet outside the outer margin of infection of a larger spot. Those observed in 1927 were located, on the average, about 15 feet beyond the limit of infection of the nearest spot, but in most cases they were in areas that had several years previously shown infection.

These small points of infection did not appear until very late in the season, and so far as could be ascertained they were separate and distinct from the larger spots near by. The soil in practically all of the experimental plots on the Greenville station is inhabited by crawfish and numerous earthworms of extraordinarily large size. It is possible that these small isolated spots originate from infection carried by such migrating soil inhabitants, although no proof is available to support this theory.

While isolated new spots of infection have been very rare at Greenville, there may be some significance attached to the fact that they occurred following a year of heavy spore production. Opposed to this theory is the fact that if these spots represented infection due to spore growth they might be expected to appear at considerable distance from the parent spots as well as near by. This has not been the case, however, as all of them are located near larger and older spots, which increases the probability that the infection, if not remaining in the soil for several years, was carried to these new locations by some soil inhabitant. No connection between the small isolated spots and the larger near-by spots could be established by examination of the plants above ground or by careful excavation of the infected roots.

During the period from 1920 to 1927 there had not been a single case at the Greenville station of a new root-rot spot having formed in what has hitherto been known as clean land at a distance greater than 25 feet from an older spot.

GRADUAL EXTENSION OF DISEASED AREAS

The spread of cotton root rot at Greenville is normally in ever-widening circles, with some advance into new ground being made each year. The percentage of infected area on all station plots from 1920 to 1927, inclusive, is given in Table 1 and shows the yearly increase of the disease on each plot. The infected area was determined by the use of a planimeter on maps drawn to scale. There

has been a general and definite trend toward an increased area of infection each year. Figure 1 illustrates graphically the extent of the spread of the disease during the 8-year period from 1920 to 1927, inclusive. During this time the area of infection has more than doubled, and in the plots continuously cropped to cotton it has trebled.

TABLE 1.—*Percentage of area of station plots infected with cotton root rot from 1920 to 1927, inclusive, at Greenville, Tex.*

[Plot size, 1 acre]

Plot	1920	1921	1922	1923	1924	1925	1926	1927
A–8	0	0	0.5	2.9	5.7	3.0	5.2	14.6
A–9	24.9	40.9	49.6	57.0	67.0	44.6	26.3	29.1
A–10	15.9	28.2	42.6	48.0	Oats.	55.5	Oats.	[1] NC
A–11	18.2	21.1	30.5	38.4	Oats.	49.0	Oats.	NC
B–1	13.9	17.5	.8	4.9	10.6	25.3	25.6	7.9
B–2	.4	2.3	4.8	9.5	12.8	17.1	23.7	27.3
B–3	0	0	.5	2.0	3.4	4.6	6.8	10.3
B–8	4.1	8.0	10.3	13.6	16.4	20.8	25.0	30.9
B–9	4.3	6.5	7.8	10.6	12.9	19.3	24.2	29.7
B–10	17.8	30.4	33.5	39.6	Oats.	47.8	Oats.	44.4
B–11	7.2	8.0	11.9	16.0	Oats.	25.9	Oats.	16.6
C–1	NC	NC	NC	NC	NC	NC	60.3	67.0
C–2	NC	NC	86.4	95.4	97.4	NC	NC	NC
C–3	6.0	14.6	20.0	28.1	32.7	39.5	NC	32.4
C–6	0	.5	3.3	6.3	11.8	15.7	11.3	17.4
C–7	0	5.2	19.6	23.6	31.6	40.5	39.1	50.9
C–8	8.7	11.7	16.3	19.5	21.9	25.3	27.4	33.8
C–9	36.8	41.6	46.7	50.1	52.9	55.3	60.0	65.4
C–10	12.2	Oats.	Oats.	Oats.	0	0	.9	7.5
D–2	NC	NC	[2] Sp.	Sp.	Sp.	71.7	87.1	NC
D–3	16.8	22.6	31.0	32.8	38.3	2.5	10.7	22.0
D–4	34.7	41.6	46.8	53.6	58.5	3.7	23.9	45.4
D–6	.4	2.9	5.6	2.1	NC	3.5	7.8	NC
D–7	50.6	67.5	79.7	NC	NC	73.7	82.3	NC
D–8	37.2	49.3	58.0	NC	NC	45.7	55.2	NC
D–9	0	0	.3	NC	NC	.5	2.4	4.1
D–10	1.4	Oats.	Oats.	Oats.	0	0	0	0

[1] NC indicates that a part of the plot was fallow or in crops other than cotton.
[2] Sp.=Sporadic.

As root-rot measurements were recorded only on the cotton plantings, a continuous record of infection for each plot is not available. The gradual increase of infection in the plots planted continuously to cotton is very apparent, although there are several striking examples of infection increasing for a number of years, then falling back to a smaller amount and beginning the growth over again. Such phenomena are illustrated in the behavior of plot A–9 in 1925, B–1 in 1922 and 1927, and D–3 and D–4 in 1925. On the plots cropped to cotton continuously, the total infected area increased from 1.45 acres in 1920 to 3.84 acres in 1927.

The most striking and significant behavior shown in Table 1 is the absence of the disease on plots C–10 and D–10 following three years of oats. The return of infection on C–10 in 1926 and 1927 was due to invasion from an adjoining plot and not to recurrence of the disease within the old area of infection.

That the spread of the disease is more or less uniform in every direction and not mainly lengthwise of the cotton row, as is sometimes supposed, is very well illustrated in Figure 1. This uniform spread of the disease may lend support to the opinion of some investigators that the disease travels through the soil regardless of root contact. There is little or no evidence at Greenville that the disease is

spread or carried to clean land by work animals or tillage implements. If it were spread in this manner, the disease would be expected to travel more rapidly in the direction of the cotton rows, and the borders of infection across the ends of the rows might be expected to be more irregular than along the sides of the spots where the spread would be across the rows.

Peltier et al. (*5, p. 10*)[1] have recently reported the advance of root rot in alfalfa under irrigation in Arizona to be "1 to 2 meters a month over a period of about seven months." They also state that "in

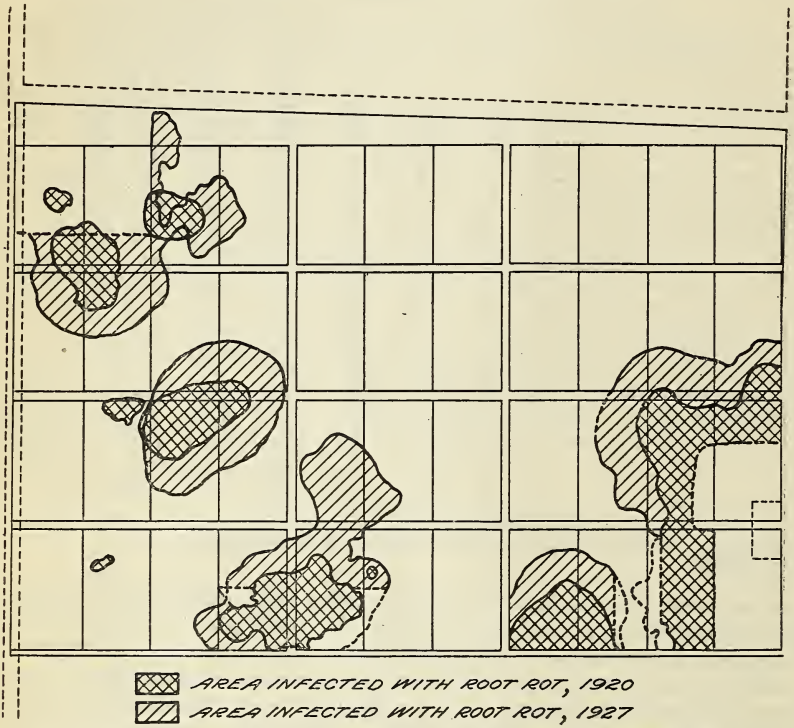

FIGURE 1.—Location and extent of cotton root-rot spots on the United States Cotton-Breeding Field Station at Greenville, Tex., in 1920 as compared with the outer margins of infection in 1927. The increased area of infection has been largely due to the extension of the original spots rather than to the formation of new spots

cotton fields the rate of spread under both dry-land and irrigated conditions is very erratic, and no exact measurements can be given." Pammel (*4, p. 11*) in 1889 stated that "the 'dead patches' have no definite boundary, extending in all directions through the field; occasionally the black streaks and patches contain a few green plants." The rate of spread at Greenville has been remarkably consistent and regular on plots continuously cropped to cotton. In some years the marginal rings were not sharply defined, but the infected areas usually showed an increase in diameter equal to the width of the marginal rings, whether or not they were prominently outlined.

[1] Italic numbers in parentheses refer to "Literature cited," p. 16.

Border ring of dead plants on outer edge of root-rot spot in 1926: A, Uninfected area; B, border ring (plants removed from foreground); C, green plants occupying position of border ring in 1925. The advance of the disease in 1926 was equal to the width of the border ring B

Banded growth of conidial mat as it appeared October 19, 1926: A, Stromatic mycelium; B, band of conidiophores; C, spore mass. (Natural size)

The yearly spread in cotton at Greenville, therefore, is generally outward in circles, as in alfalfa, and there is often a tendency for the plants to remain alive longer in the area occupied by the border ring of the preceding year. (Pl. 1.) A scattered growth of green plants is sometimes present throughout the infected area, although they are usually plants which have been attacked by the disease but have maintained themselves by throwing out shallow lateral roots.

GROWTH OF INDIVIDUAL SPOTS

At Greenville, Tex., cotton root rot normally spreads in a succession of annual, ever-widening circles or concentric rings, in much the same manner as is common among other fungi which form "fairy rings." King (*1*, *2*) has given an excellent description of the circular spread of root rot in alfalfa fields in Arizona, and has also observed it in cotton. Scofield (*6*, *7*) observed the "tendency for the spread of the disease to take place like the spreading of a fairy ring," although he states that it was not very pronounced at the San Antonio Field Station. The senior writer (*3*) later described progressive circular spread in cotton at Greenville.

Crescent-shaped areas of dead cotton plants are of common occurrence in most cotton fields infected with root rot. They become visible early in the season and are most common along the outer borders of infection. These border rings of dead plants apparently mark the new advance of the disease for that year, or if the ring is within an area of old infection it may mark an advance of reinfection. At Greenville the border rings average 10 to 12 feet in width, while King (*1*, *2*) reports the increase in diameter for circles in alfalfa in Arizona as about 8 meters per year and that in cotton the circles increase in diameter about 9 meters in 50 days. The advance in cotton at Greenville is therefore practically the same as for alfalfa in Arizona, although probably considerably less than that reported for cotton in Arizona. Figure 2, showing the annual outer margin of infection of a root-rot spot for a period of eight years, illustrates the regularity with which the disease often spreads outward into new ground.

For comparison with Table 1, showing the percentage of infection in each plot from 1920 to 1927, inclusive, Table 2 has been prepared showing the growth of seven root-rot spots over the same period of years. During this 8-year period 4 of the 7 spots expanded until they merged, forming fewer but larger spots.

TABLE 2.—*Growth of individual root-rot spots from 1920 to 1927, inclusive, at Greenville, Tex.*

Spot No.	Location	1920	1921	1922	1923	1924	1925	1926	1927
		Acres	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
1	A–8, A–9, A–10	0.26	0.38	0.56	0.68	0.72	0.56	[1] Sp.	Sp.
2	A–10, A–11, B–10, B–11	.53	.70	1.11	1.32	Oats.	1.70	Oats.	[2] NC
3	A–10, A–11	.03	.08						
4	B–8, B–9, C–8, C–9, C–10	.54	.67	.81	.93	1.04	1.18	1.31	1.54
5	D–3, D–4	.51	.64	.77	.86	.96	.06	.31	.67
6	C–6, C–7		.05	.22	.29	NC			
7	D–6, D–7, D–8, D–9	.87	1.19	1.43	NC	NC	1.77	2.01	NC
	Total acreage infected	2.74	3.71	4.90			5.27		

[1] Sp.=Sporadic.
[2] NC indicates that a part of the plot was fallow or in crops other than cotton.

There has been a general tendency toward a gradual increase in size of all spots on the farm, although the rate of spread has not always been the same. Spots 2 and 3, which showed a combined area of 0.56 acre in 1920, grew to 1.70 acres in 1925. Spot 4, with 0.54 acre in 1920, reached 1.54 acres in 1927. Spots 6 and 7 increased from a recorded 0.87 acre in 1920 to 2.01 acres in 1926. The combined area of all the spots increased in size from 2.74 acres in 1920 to 5.27 acres in 1925, practically doubling in size in five years

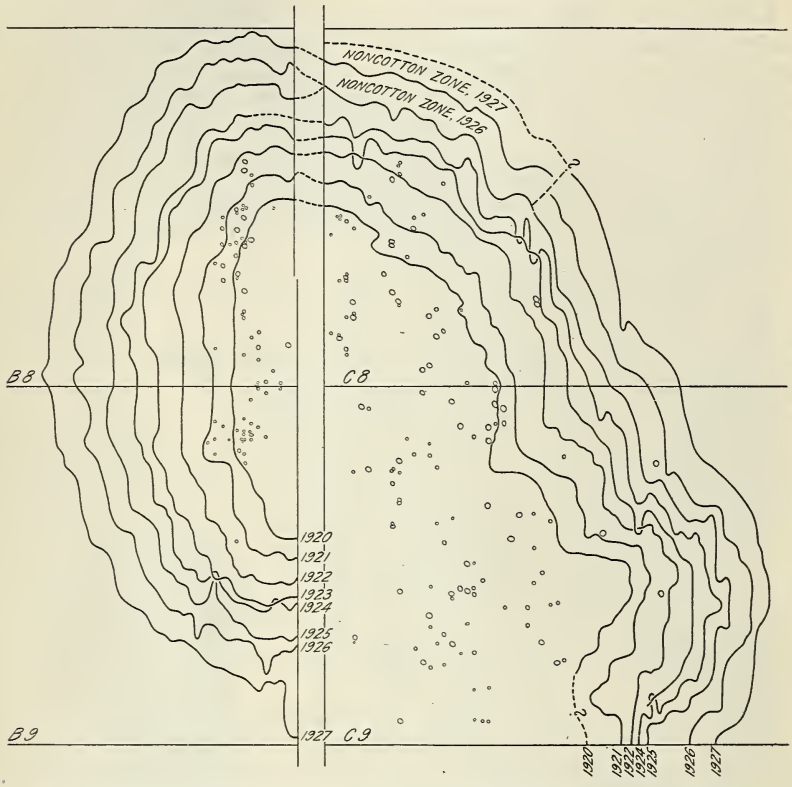

FIGURE 2.—Circular and uniform spread of root rot as indicated by the yearly location of the outer margin of infection over the 8-year period from 1920 to 1927. The small round figures near the center represent the location and relative size of spore mats formed during October, 1926. About 90 per cent of these mats fall within an area that has shown infection each year since 1921 and possibly several years prior to 1921

(Table 2.) A corresponding increase was recorded for practically all spots on which cotton was planted in 1927. An annual increase in size of the spot does not always mean a greater crop loss, for in some years a considerable number of plants survive within an old area of infection, and occasionally heavy losses do not occur until late in the season. The actual loss of the crop from root rot is governed by the percentage of plants that die within an infected area and the time of season that they die. Some plants mature a crop of bolls before dying.

In central and southern Texas, where the growing season is longer than at Greenville, root rot undoubtedly makes a greater advance each season. During the summer of 1927 cotton plants began dying near Austin about three weeks earlier than at Greenville and continued to die nearly a month later in the fall. In regions where the growing season is longer it is probable that the spread is greater, although no definite comparisons are yet available upon this point.

Occasionally a spot has shown a steady increase in size for a number of years and then undergone a breaking up of the infected area into a number of small isolated spots, which began the growth anew. The behavior of the disease on plots D–3 and D–4 is a good illustration of this phenomenon. The infection on these two plots increased yearly from 1920 to 1924. In 1925, which was a very dry year, the infection dropped to 2.5 per cent on D–3 and 3.7 per cent on D–4, as compared with 38.3 and 58.5 per cent, respectively, in 1924. In 1926 the two plots showed 10.7 and 23.9 per cent infection, and in 1927, 22.0 and 45.4 per cent, respectively. A similar condition was observed on plot A-9 in 1925.

The breaking up of a spot into smaller isolated areas appeared to be an independent function of the spot and, in some cases at least, may be associated with the age of the spot. As an illustration, plot B–1 contained only one spot in 1920, but in 1921 another spot invaded the plot, and later the two spots merged. The first spot increased in size from 1920 to 1921 and broke up in 1922 into a number of very small spots. (Table 1.) These small spots then began their growth anew, gradually reforming the original spot, which finally merged with the second spot that invaded the plot in 1921. Then, five years later, in 1927, the first spot again broke up into a few small spots, but left that portion of the spot which invaded the plot in 1921 intact, practically all the plants on it being killed.

The spot that broke up was on land that had been worked wet and planted to potatoes in February. The potatoes rotted, and the land was later bedded and planted to cotton. It appeared for some time that the different cultural treatment might be responsible for this effect, but a comparison of the maps of several years indicates that the behavior was due to a condition that brought about the independent breaking down of one spot, with apparently no effect upon the contiguous spot with which it had merged. The separation of the two spots appeared to be complete and their behavior independent.

DEATH OF PLANTS IN OLD SPOTS

To determine the rate of dying of the plants in areas of old infection, the plants on plots B–3, C–2, and C–3 were tagged daily, with dated tags as they died, during the summer of 1926. Tagging was begun July 26, when the first plants began to die, and was continued until September 30. The locations of the dead plants in the row, together with the dates on which they died, were plotted at the end of the season.

In this study the first isolated plants to die were considered as individual centers of infection. New centers and groups of dead plants continued to appear from the early part of the season until the tag-

ging was discontinued, showing that the fungus was more widely distributed than the early centers indicated. The mean daily extension of dead plants in the row was computed by dividing the total distance that the disease was supposed to have traveled, from the first dead plant for each center of infection to the last consecutive dead plant for each center, by the total number of days between the death of the first and of the last plant. The mean daily rate of spread on plot B–3 was 0.0917 foot while on plot C–3 it was 0.1075 foot per day.

The time covered by the tagging operation was 67 days, and it included a period when the disease is normally very active. On the basis of the mean daily rate of spread along the row, the spread on plot B–3 totaled 6.14 feet and that on C–3 7.20 feet for the 67-day period.

Most of the tagged plants were located well within the margins of old infection and died at irregular intervals. The spread from the centers of infection was irregular, and in only a few instances did the plants die uniformly in both directions from the points where the first plants died. In some cases no spread of infection occurred in either direction.

GREATER DESTRUCTIVENESS OF THE DISEASE WHEN ADVANCING INTO NEW GROUND

At Greenville it has often been noted that where marginal rings of new growth are observed the destruction of plants is more complete than in the areas of old infection.

After studying the rate of dying of plants in an area of old infection, a study of the rate of advance of the marginal ring was made in 1927. The first plants to die on the outer edge of a spot were marked with dated tags, and as succeeding plants in the row died they were marked, and so on until the end of the season.

The advance of the disease at the end of the season of 1926, the date and position in the row of the first plant to die in the previously uninfected area, together with the date and position in the row of the last plant to die at the end of the season, are given in Table 3. This table shows that the disease made a mean outward advance of 10.21 feet along the row for the season, or a daily advance of 0.1264 foot into new ground. The season of active killing of plants in new ground did not exceed 109 days, the mean number of days required for the advance being 80.75. In some cases the first plants to die were within the area of old infection, but such plants are not included in Table 3. In contrast with the erratic behavior of the spread from the various points of infection within the area of old infection, the outward advance of the marginal ring into new ground has been very regular and appears to be somewhat more rapid.

TABLE 3.—*Distance from the edge of the plot to the outer margin of root-rot infection in 1926, and distance of new advance into previously uninfected land in 1927, together with the date when first and last plants died and number of days from death of first to death of last plant in each row*

[Measurements are given in feet from the edge of the plot]

Row No.	Distance from edge of plot to—		Date first plant died	Distance from edge of plot to last dead plant in new zone	Date last plant died	Total advance	Time required
	Outer margin of infection	First dead plant in new zone					
	Feet	*Feet*		*Feet*		*Feet*	*Days*
1	57	60	July 30	71	Oct. 30	11	93
2	59	60	July 18	72	Oct. 31	12	105
3	56	56.5	July 12	71	Oct. 15	14.5	95
4	58	58.5	July 27	69	Oct. 31	10.5	96
5	56	60	July 13	70	Oct. 30	10	109
6	55	59	Aug. 19	68	Oct. 5	9	37
7	57	61	Aug. 2	71	Oct. 4	10	63
8	57	63	July 28	72	Oct. 5	9	69
9	58	61.5	July 13	77	Oct. 20	15.5	99
10	60	67	July 19	79	Oct. 4	12	77
11	65	67.5	Aug. 3	80	Sept. 26	12.5	54
12	69	73.5	July 27	79	Sept. 24	5.5	59
13	71	73	Aug. 1	80.5	Oct. 17	7.5	77
14	72	72	July 19	84	Oct. 30	12	103
15	73	75	---do----	84	Oct. 5	9	78
16	74	78	Aug. 10	83	Sept. 16	5	37
17	79	81	July 28	90	Oct. 27	9	91
18	79	81	July 19	89	Oct. 31	8	104
19	78	80	July 13	89	Oct. 5	9	84
20	77	78	July 10	91	Sept. 26	13	74
21	78	82	July 15	93	Oct. 25	11	108
22	79	82	July 16	91.5	Oct. 30	9.5	102
23	77	78	July 19	90	Oct. 5	12	76
24	78	78.5	Aug. 4	87	Sept. 17	8.5	48

In fields where the advance of the disease has been more or less regular the first plants to die are usually along the outer edge of the location of the marginal ring of the previous year, and then while the marginal ring is gradually reaching its full extension the plants back of the ring and within the area of old infection may gradually die out. This behavior is well illustrated by Figure 3, which shows the distribution of dead plants in a part of a large root-rot spot on August 10, soon after the plants had begun to die, and the condition at the end of the season.

The summer of 1927 was favorable for the progress of the disease, and practically all of the plants within the spot died by the end of the growing season. (Fig 3.) Although the marginal ring was well defined in outline on August 10, it made an additional advance outward of 6 to 8 feet by the end of the season.

In root-rot spots where the marginal ring is well defined, a zone of green plants often persists throughout the season just inside the ring, occupying the location of the marginal ring of the previous year. The senior writer (*3*) has shown this condition as it existed at the end of the season on a spot at Greenville for four successive years. Plate 1 shows a marginal ring of dead plants on the outer edge of a root-rot spot just behind which is a band of green plants occupying the area on which the marginal ring was located the previous year. This behavior makes the analogy to fairy-ring fungi more pronounced and suggests that the fungus uses up the food

supply as it advances or gives off a toxin which is not dissipated for some time. If the season is dry this zone of green plants may persist, but if conditions are more favorable for the fungus the plants die after the marginal ring begins to form.

OCCURRENCE OF FRUITING BODIES IN RELATION TO MARGINS OF DISEASED AREAS IN 1926

During the usual dry summers at Greenville, fruiting bodies in root-rot areas have been observed only occasionally, but with the humid conditions that prevailed during the summer and fall of 1926 conidial mats were produced in abundance.

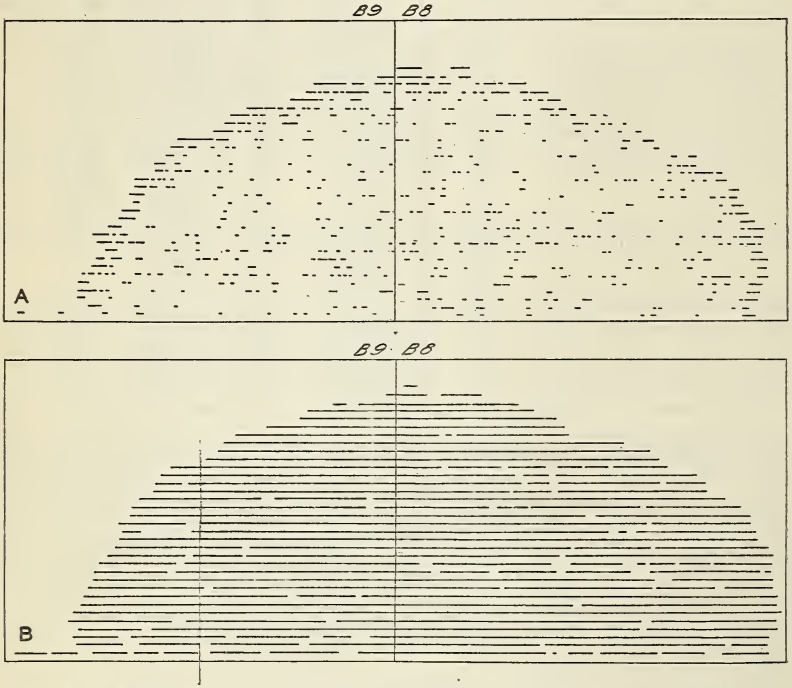

FIGURE 3.—A. Distribution of plants dead of root rot on a portion of a large spot on August 10, 1927, soon after the plants began to die; B, distribution of dead plants for the same spot at the end of the season

On August 2 a single small conidial mat, already several days old, was observed. Although a careful lookout was maintained, no more mats were found until the middle of October. Following several warm, rainy days during the week of October 11 to 16, a large number of spore mats developed in a majority of the infected plots on the station. Some of the mats made a very vigorous growth, reaching a diameter of 40 to 50 centimeters. A sudden drop in temperature, accompanied by 0.08 inch of cold rain on the night of October 19, checked all further growth of the mats for the season.

The conidial mats in most cases showed the characteristic banded appearance with the whitish stromatic mycelium advancing on the outer edge, followed by the dense band of young conidiophores, back

of which was the depressed area of tan-colored spores. The banded growth of a spore mat is shown in Plate 2.

In studying the occurrence of the spore mats it was observed that they often held a definite relation to the infected areas. Some of them were located along the periphery of the diseased area, but others were in definite formations well within the area. In view of the fact that this last behavior had not heretofore been described, mapping of dead plants was begun at once, and the location and relative size of each spore mat in the row was also recorded. The outer margin of infection from 1920 to 1927, together with the location of the spore mats in a large spot in 1926, is shown in Figure 2.

From this map showing the location of conidial mats it will be observed that about 90 per cent of the mats occurred within the area that was infected in 1921 and for several years prior to 1921. While the disease has made a regular advance outward each year since 1921, there were relatively few fruiting bodies in the area that had become infected since that year. This indicates that when a favorable opportunity is afforded, the fungus may come into more prolific fruiting after certain conditions are produced by long infection.

A similar behavior was observed on plots C–6 and C–7. Several small root-rot spots, which were first observed and mapped in 1921, gradually increased in size until 1925, when they merged with a much larger spot that had developed apparently from older infection. In mapping the area in 1926 as one large spot, only a single small conidial mat was found on that portion of the spot which had developed since 1921, but large numbers were found in the area of older infection.

Another interesting behavior in regard to the fruiting of the fungus was observed on plots D–3 and D–4. A root-rot spot extending into these two plots had gradually increased in size until in 1924 it had attained an area of 0.96 acre. (Table 1.) In 1925 this spot broke up into a number of small isolated points of infection aggregating only 0.06 acre, which in 1926 increased to 0.31 acre and included 15 distinct spots. On these 15 small spots 30 spore mats were observed and mapped and in every case were found to be located on the periphery of the infected spots. Twenty-four of the thirty mats were located in an area that was infected in 1921 and for several years prior to that time. None of the fruiting bodies were on the inside of the spots or near the points where the infection was carried over from 1925, but definitely on the outer edge which marked the limits of infection for 1926. This behavior differs somewhat from the foregoing case in that the location of all the spore mats with respect to infection are marginal, while in Figure 2 they are centrally located. The writers are unable to offer an explanation for this variation in behavior. It may have some relation to the food supply in the soil or to the stage of life history of the fungus when the favorable fruiting conditions occurred.

GREATER LOSSES IN EARLIER PLANTINGS

That root rot is not so destructive in late-planted cotton as it is in early planting is known to most students of the disease (*8*). A date-of-planting experiment in which the cotton rows extended for a short distance into a root-rot spot presented an opportunity for

comparing the behavior of the disease on cotton planted on June 1 with a planting made on April 29.

Within the spot under observation the plants had died out completely in 1926, while in 1927 the disease was not so destructive and the loss of plants was not so great. Notwithstanding this difference in the behavior of the disease, there appeared early in the season a very definite tendency for the plants in the earlier planting to die of root rot. On July 26 there were no dead plants in the June 1 planting, while a considerable number in the April 29 planting were dead. Even at the end of the season, when the final measurements were recorded, there were only a few plants dead in the June 1 planting where it extended into the infected spot. In another spot some distance away the June 1 planting showed a substantial loss of plants when they were mapped on October 28, although none were dead on July 26, when the first measurement was made.

The distribution of dead plants in the April 29 and June 1 plantings in 1927, together with the location of infection for 1926, are

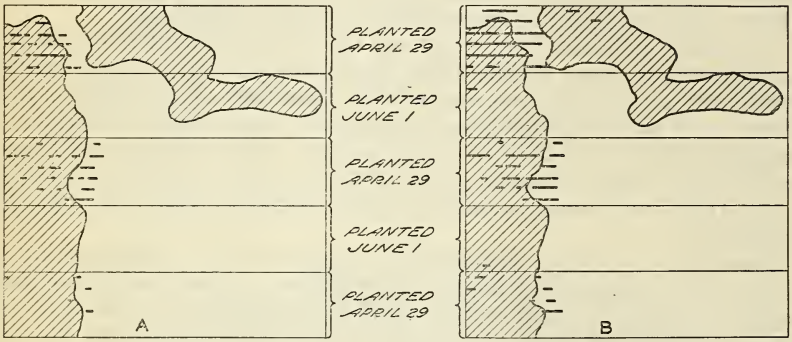

FIGURE 4.—Comparative number of plants dead of root rot in April 29 and June 1 plantings on July 26 and October 28, 1927, as indicated by the heavy black horizontal lines. The shaded portion represents the area of infection in 1926. A, Location of dead plants July 26, 1927; B, location of dead plants October 28, 1927

shown in Figure 4, and indicate that the disease is more destructive in early plantings of cotton.

When cotton roots reach a half-grown stage they show an orderly development of root lenticels along the taproot which are arranged in pairs with each of the four ranks of lateral roots. Sometimes they may be absent or their position obscured by a deformed growth of the root, but their normal arrangement in pairs attending each rank of lateral roots is very definite. Root lenticels may also be found on the lateral roots. They have not been observed at Greenville until the root system is well developed, and they are most apparent during rainy seasons or when the ground is moist. The histology of these root lenticels indicates that they offer the fungus easy access to the living root tissues. Whether their development renders the plants more susceptible to the attack of the fungus and whether their appearance is associated with a greater root development, which would increase the chances of infection, are questions that deserve further study. Possibly both contribute to increase plant losses. The regular arrangement of root lenticels on the taproots of cotton plants is shown in Plate 3.

Well-developed healthy cotton roots and root lenticels arranged in pairs along each rank of lateral roots

A, Locations of 12-inch barrier and effective manner in which it retarded the advance of the disease; B, side view of 24-inch barrier retarding advance of disease and showing additional advance where not stopped by barrier. (Photograph August 23, 1927)

EXPERIMENT WITH TRENCH BARRIERS

In experimenting with different cultural practices on root rot and putting them into operation, some understanding of the depth of the advancing zone of mycelium at different times of the season would be of value. Live mycelium has been found frequently on cotton roots at Greenville at depths ranging down to 26 inches. The advancing zone as it moves through the soil may not be as deep as it often is on roots. It is probable, however, that the depth at which the mycelium operates may fluctuate considerably under the influence of soil and climate.

To determine as nearly as possible the depth of the mycelial zone, two "trench" barriers were dug 3 to 4 feet in front of the outer margin of infection of the previous year on plot B-2 on June 27, 1927. One of these barriers was 12 inches deep and the other 24 inches deep, each being about 25 feet long and lined with 12-inch boxing plank to

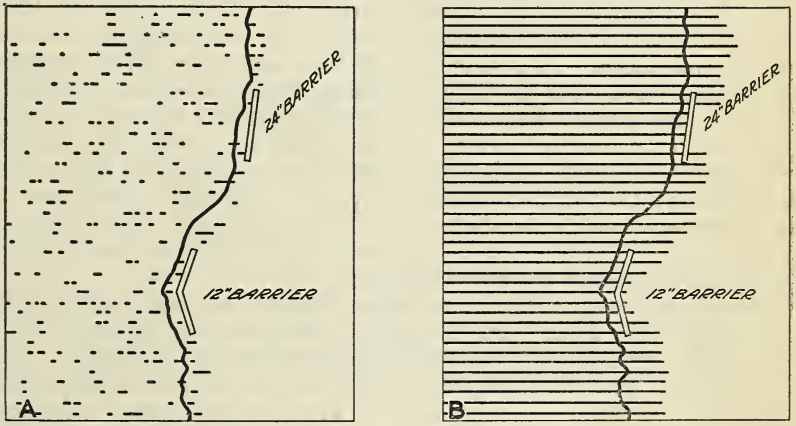

FIGURE 5.—Location of the 12-inch and the 24-inch barriers on plot B–2 and the distribution of dead plants on July 26 (A) and (B) on October 28, 1927. The heavy black line across the rows shows the position of the outer margin of infection in 1926

prevent caving of the side walls. The lined trench walls were about 8 inches apart. Figure 5 shows the arrangement of barriers on plot B–2 and the location of dead plants on July 26 and October 28, 1927, in relation to the outer margin of infection for 1926.

When observations were made on July 13 the cotton plants had died on the inner or diseased side up to the barriers, but in the undisturbed rows the disease had advanced several feet farther than in the adjacent rows, where it had apparently been checked by the barriers. By August 1 the root rot had advanced well beyond the ends of both of the barriers, and by September 1 it appeared that both the 12-inch and 24-inch barriers would effectively block further advance of the disease. (Pl. 4.) It was not until September 17 that the first plant in the center rows on the outer side of the 12-inch barrier died, but by September 26 several plants on the outer side of this barrier were dead from infection due either to penetration of roots beneath the 12-inch barrier or from advance of the fungus through the soil at the bottom of it.

After the disease had advanced to the outer edge of the corners of the 24-inch barrier it made a rapid radial spread and overlapped the first two rows on the outside of the barrier at one end and one row at the other end. With the exception of the activity on these three rows there was no further dying of plants on the outer side of the 24-inch barrier, which indicated very definitely that the advance had been blocked, for the current year at least.

In excavating the trenches an abundance of small rootlets of plants developed in previous years was found at a depth of 24 inches, and in later excavations the rootlets were found to be plentiful at a depth of 4 feet.

EXPERIMENTS WITH CLEAN FALLOWS

Studies with clean fallows were begun in 1922 and have been continued since that year. Two experiments with 1-year and 2-year clean fallows have been completed, and numerous other experiments with fallows, rotations, and additions of organic matter are under way. A 1-year clean fallow may temporarily reduce root-rot infection, but it gives little permanent relief and not enough to recommend its use alone. A 2-year clean fallow has given very encouraging results. One plot that showed more than 90 per cent infection for the 3-year period from 1919 to 1921, inclusive, showed no infection when returned to cotton in 1924 after a 2-year clean fallow. Even after the fourth successive cotton crop on this plot, there is no recurrence of the original diseased spots. Although some root rot has appeared within the 2-year fallow plot, it was clearly due to invasion from infection in an adjoining plot and not to infection carried over through the 2-year fallow.

In one experiment with 2-year clean fallows the only plants to die in the plot aside from some marginal invasion were in an area beneath which decomposed roots of a mulberry tree were located. The mulberry tree was blown down in 1920, and no further signs of life appeared from the roots afterwards. The tree had apparently been dead seven years, and some significance may be attached to the fact that the plants died only in the area occupied by the decomposed mulberry roots.

In several instances a 1-year clean fallow has apparently had the effect of arresting the early appearance of the disease. In some cases the first plants to die on plots that have been in clean fallow for only one year died three to four weeks later than those in adjoining continuously cropped cotton plots. In other experiments 1-year clean fallow showed no advantage over plots continuously cropped to cotton in so far as the appearance of the disease was concerned. Cotton on the fallow plots has always shown more vigor than on the continuously cropped plots. A fallow treatment which includes an operation conducive to the deep drying out of the soil as well as the destruction of all live plant material is very desirable. Some experiments have indicated that greater benefits might be derived from the deep drying out of the soil than from frequent surface tillage.

While clean fallows are expensive to maintain and their use can be recommended in only a limited way, they have a very stimulating effect upon plant growth. This is especially true of the 2-year clean fallows, on which the vigorous growth of the plants has been

very outstanding as compared with that on adjoining plots continuously cropped to cotton.

Possibly the greatest practicable value of clean fallows and clean culture will be in combination with various rotations.

SUMMARY

Records of the location and distribution of root rot on all plots of the United States Cotton-Breeding Field Station at Greenville, Tex., have been made since 1920, and these records of infection for the 8-year period from 1920 to 1927, inclusive, form the basis of this report.

Cotton root rot is indigenous to many districts in Texas, and the infection may be of longer standing than generally supposed.

The increase in area of root-rot infection on the Greenville station has been due to growth and expansion of the spots already in existence when the area was originally mapped in 1920, rather than to the formation of new spots. Plots continuously cropped to cotton during the 8-year period 1920–1927 have an area of infection about three times greater than the area infected in 1920.

The mean daily rate of spread of the infection from various centers in an area of old infection in 1926 was 0.0917 foot on plot B–3 and 0.1075 foot on C–3.

The mean daily rate of advance of the marginal ring was 0.1264 foot on plot B–2 in 1927.

In early-planted cotton losses from root rot are usually greater than in later plantings.

Cotton root rot at Greenville normally spreads in ever-widening circles and in a rather uniform manner. The disease apparently spreads across the rows at about the same rate that it travels along the row. There is no evidence to indicate that the infection is carried through the field by tillage implements or on the feet of work animals.

Usually the first plants in a spot to die are those on the outer border of the infection of the previous year. The mortality of plants in the border ring is usually higher than that of those in the interior of the spot.

The fruiting stage of the root-rot fungus is attained only occasionally at Greenville. In 1926, when there was heavy spore production following a humid summer and fall, the fruiting bodies appeared to be associated with a certain stage of growth or long standing of the disease.

A preliminary experiment with barriers, consisting of narrow trenches 12 and 24 inches deep, indicates that the advancing zone of the mycelium is not deep seated in the soil at Greenville; possibly it extends about 12 inches, but it does not go as deep as 24 inches. Active mycelium has been found on the roots of the cotton plants at a depth down to 26 inches, but ordinarily it is found at a depth of not more than 15 inches.

A clean fallow for one year may or may not give temporary relief from root rot, but in some cases it apparently has arrested the appearance of the disease for three or four weeks.

A 2-year clean fallow has given encouraging results. Since 2-year clean fallows are expensive to maintain, their use can be recom-

mended only in a limited way. Possibly the greatest practical value of clean fallow treatments will come in connection with its supplemental use in rotations with nonsusceptible crops.

LITERATURE CITED

(1) KING, C. J.
1923. COTTON ROOTROT IN ARIZONA. Jour. Agr. Research 23: 525–527.
(2) ———.
1923. HABITS OF THE COTTON ROOTROT FUNGUS. Jour. Agr. Research 26: 405–418, illus.
(3) MCNAMARA, H. C.
1926. BEHAVIOR OF COTTON ROOTROT AT GREENVILLE, TEX., INCLUDING AN EXPERIMENT WITH CLEAN FALLOWS. Jour. Agr. Research 32: 17–24, illus.
(4) PAMMEL, L. H.
1890. COTTON ROOT-ROT. Tex. Agr. Expt. Sta. Bul. 7, 30 p., illus.
(5) PELTIER, G. L., KING, C. J., and SAMSON, R. W.
1926. OZONIUM ROOT ROT. U. S. Dept. Agr. Bul. 1417, 28 p., illus.
(6) SCOFIELD, C. S.
1919. COTTON ROOTROT SPOTS. Jour. Agr. Research 18: 305–310, illus.
(7) ———.
1921. COTTON ROOTROT IN THE SAN ANTONIO ROTATIONS. Jour. Agr. Research 21: 117–125.
(8) TAUBENHAUS, J. J., and KILLOUGH, D. T.
1923. TEXAS ROOT ROT OF COTTON AND METHODS OF ITS CONTROL. Tex. Agr. Expt. Sta. Bul. 307, 98 p., illus.

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